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Art. III.—*Orthite in Some Victorian Granitic Rocks.*

By GEORGE BAKER, M.Sc.

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Introduction.

A search for the cerium-bearing epidote mineral known as orthite or allanite in Victorian granitic rocks, subsequent to its discovery in the You Yangs granite (1), has revealed its presence in granitic rocks occurring at Tynong, Mt. Eliza, South Morang, Zumstein's Crossing in the Grampians, Selby, Yackandandah, Mt. Wycheproof, Maude, Junction of the Mitta Mitta River and the Bundarrah River, Stawell, Dergholm, and Tarnagulla. The majority of these outcrops present evidence of having been contaminated by assimilation. The orthite crystals are of microscopic size and occur too sparsely for chemical analysis.

Mode of Occurrence.

The orthite is not of common occurrence, and most of the crystals so far observed are found in granitic rocks containing xenoliths or basic clots and schlieren. The greatest concentration occurs in basic schlieren at the You Yangs, where orthite locally constitutes 3.5 per cent. of the rock, and sometimes occurs in groups of three or four crystals wedged between biotite and hornblende (fig. 12). In the granitic rocks, the orthite would represent only a small fraction of 1 per cent., and it usually occurs as more or less idiomorphic, isolated crystals. Biotite is moulded around many of the orthite crystals, and a few lie in contact with sphene and hornblende. Several occur independently of the ferromagnesian minerals and are surrounded by quartz or felspar.

The following table indicates the distribution of observed crystals of orthite in Victorian granitic rocks. The minerals listed as associated minerals are those which are most frequently found in direct contact with the orthite crystals. Biotite, quartz, and felspar are omitted from the list because, being the important essential minerals of the rocks in which the orthite occurs, they are commonly found associated with many of the orthite crystals.

A total of 409 rock sections from the University collection was examined for orthite, this number representing about 100 different localities of granitic rocks in Victoria. Of the total number, 178 sections were from rocks collected from the thirteen localities listed in the table, but only 43 of them were found to contain orthite. The totals for each rock type examined are as follows:—Granites, 147 sections, granodiorites (including the

TABLE I.

	Location.	No. of Slides Examined.	No. of Slides with Orthite.	No. of Orthite Crystals.	Associated Minerals.			Xenoliths.
					Hornblende.	Sphene.	Epidote.	
Granites.	You Yangs	38	9	23	x	x	..	x
	Dergholm	5	1	1	x	x	x	x
	Stawell	4	4	17	..	..	..	..
	Mitta Mitta Bundarrah River Junction ..	2	1	1	..	..	x	..
	Maude	2	1	3	..	x	..	..
	Mount Wycheproof	2	1	1	..	..	x	..
	Tynong	8	2	8	x	x	..	x
Granodiorites.	Tarnagulla	2	2	3	x	x	..	..
	Mount Eliza	2	1	1	x	x	..	x
	South Morang	3	1	1	x	x	..	x
	Zumstein's Crossing, Grampians	2	1	2	x	x	..	x
	Selby	2	1	2	x	x	..	x
	Yackandandah	1	1	2	..	x	x	x
Basic Schlieren.	You Yangs	5	5	34	x	x	..	x
	Tynong	1	1	4	x	x	x	x
Xenoliths.	You Yangs	99	11	17	x	x	..	

so-called adamellites), 111 sections, xenoliths, 145 sections and basic schlieren, 6 sections. Out of a total of 120 crystals of orthite observed, one-third occurred in the basic schlieren of the You Yangs. Granites contained four times as many crystals as granodiorites. Ninety-six of the crystals occurred in rocks containing sphene and hornblende, whilst You Yangs rocks contained augite in addition. Five were in rocks containing sphene but no hornblende, and the remaining nineteen in rock types which possessed neither sphene nor hornblende, the Stawell granite being outstanding amongst such examples. Epidote was neither common nor widespread in the orthite-bearing rocks.

Description of Victorian Orthites.

Orthite is a monoclinic mineral, and it possesses very variable physical, chemical, and optical properties. The crystals vary in size from 0.2 mm. to almost 3 mm., and are commonly prismatic, being sometimes elongated along the direction of the c-axis (fig. 4). In cross section, some appear diamond-shaped (figs. 6 and 10), others are sub-ovoidal (fig. 9), or more or less irregular (fig. 7). Some of the orthite crystals in the granite and xenoliths from the You Yangs have been corroded in contact with biotite and hornblende (figs. 2 and 6), and others in contact with quartz and felspar (fig. 1). Sometimes the corrosion is restricted to one visible face of the crystal (figs. 3, 5, and 8). The largest and best developed crystals are found in basic schlieren from the You Yangs (1), where an occasional lens-shaped form is present (fig. 18).

The colour varies from colourless, pale yellowish-brown, pale green, greenish-brown, and deeper shades of brown to red. The deep red colouration of some altered crystals appears to be due to ferric oxide, since hematite occurs along cracks and cleavages, and outlining the other minerals in rocks which contain red orthite. Fresh cores and remnants in orthite crystals, such as those indicated by dotted areas in figures 3, 13, 14 and 20, are pleochroic from greenish-brown to reddish-brown.

Iddings records strong basal cleavage in fresh orthite (5), but no traces of cleavage were observed in any of the Victorian examples. The irregular cracks which traverse most crystals (figs. 2, 3, 7, 10, and 22), may represent (100), (110), and (010) cleavage traces, as is stated to be the case by Michel-Lévy and Lacroix in some of the French occurrences (11). Occasionally the cracks are curved as in fig. 19.

Simple twinning, with the twin plane parallel to (100), has been observed in three crystals, one of which possesses a marked "composition seam" (fig. 20), similar to that described by Hobbs (4, p. 226).

Zoning occurs parallel to the outline of the crystal form as in figs. 16 and 17, but it is often "chevron-shaped" as indicated in figs. 4, 13, 14, 20, and 23. Lacroix figures orthite crystals with zoning similar to the "chevron type" from an amphibole gneiss at Geffren-en-Roscoff (8, p. 139), and Hobbs figures similar examples from the hornblende granite of Ilchester, U.S.A. (4, p 226). Michel-Lévy and Lacroix state that nearly all of the orthite crystals from Pont Paul in France, are zoned (11), so it appears that zoning is a common characteristic of the mineral orthite.

In the Victorian granitic rocks fresh and partly altered remnants of orthite are frequently zoned by much more altered material, the nature of which is uncertain. Clarke considers that the altered material in allanite consists of carbonates of the cerium group (2), but Watson records only slight traces of carbonates in the outer zones of weathered allanite (13). The alteration zones in some of the Victorian occurrences are quite rust-coloured (fig. 17), and in others, these zones consist of indeterminable "earthy" material (figs. 4 and 5).

The pale coloured peripheral zones in orthite crystals from Tynong, Stawell, and the You Yangs, often contain dendritic inclusions of black iron oxide (figs. 3 and 21), and other crystals possess an outer fringe of similar material (fig. 11), which appears to have been derived from the alteration of fresh orthite. Other inclusions in the orthite consist of needles and stout prisms of apatite (figs. 1, 5, 18, and 19), rounded grains of diopside (fig. 1), rutile (fig. 20), and zircon (figs. 1, 5, 12, and 16). The apatite and zircon themselves contain smaller inclusions. Mennell has recorded similar inclusions from the granites of Northern Rhodesia (10, p. 3), and Iddings and Cross record inclusions of sphene in addition (6, p. 110).

Small rounded crystals of orthite are frequently enclosed by biotite (fig. 15), and rarely by hornblende (fig. 9). Michel-Lévy and Lacroix have recorded allanite crystals enveloped by biotite in the granite of Pont Paul, and state that pleochroic haloes are produced as intense as those formed by zircon (11, p. 67). This also applies to the Victorian examples, where haloes are always developed when orthite is in contact with biotite, and only in rare occurrences is a halo produced in hornblende (fig. 9), even though this mineral is often observed in contact with orthite. The haloes indicate the presence of one or more radio-active elements, and their width, which is 0.04 mm., would be due to Thorium C_2 according to Joly (7).

The variable composition of orthite is revealed in the optical characters of some U.S.A. examples according to Watson (14, p. 7), and optical examination shows that the Victorian occurrences are similarly variable. Crystals extinguish up to an angle of 45°. In one crystal from the You Yangs, a fresh inner core has an extinction angle of 30°, whilst the somewhat altered outer zone extinguishes at 15°. The refractive index varies with the degree of alteration, being much lower in the altered examples than in the fresh pleochroic portions. When very much altered, crystals of orthite become isotropic, as in some of the Mitta Mitta River-Bundarrah River junction, You Yangs, and Zumstein's Crossing examples. The fresh pleochroic cores and zones have a low birefringence, and they are biaxial and negative.

In general, the Victorian orthites conform with Watson's conclusion that isotropic allanite represents the altered form of the original crystalline mineral (14, p. 7). Larsen obtained results which indicate that birefringent crystalline allanite was secondary in some specimens, and derived from the isotropic form (9). He describes allanite crystals from U.S.A. as consisting of three minerals, a pale sensibly isotropic mineral, a weakly birefringent portion, pleochroic in green and yellow with a slightly higher refractive index, and a third more strongly birefringent with a still higher refractive index. In these variations, he considers that the oxidation of the iron present is probably an important factor These three variations are represented in the Victorian examples of orthite, where in some crystals the iron has separated out as oxides and hydrous oxides in the altered outer zones (fig. 21).

Epidote--Orthite Association.

Dana classifies orthite in the epidote group, with which it is isomorphous, and in which it may be enclosed as a nucleus (3). Iddings refers to the intergrowth of orthite and epidote in parallel orientation in some of the U.S.A. granites, and he states that the two minerals are pyrogenetic (5). Mennell records zoned orthite surrounded by epidote in a granite from Kaloma in Northern Rhodesia (10).

Orthite has been observed in association with epidote in two Victorian granitic rocks. In the Yackandandah granodiorite, two well developed crystals are fringed at the ends with small prisms of pale green epidote (fig. 22). These fringes appear to be marginal alteration products of orthite. In the muscovite granite from Mount Wycheproof, a small rounded crystal of orthite is enveloped by a narrow continuous rim of epidote, which may perhaps be due to alteration similar to that recorded by Iddings and Cross (6, p. 111). On the other hand, both the orthite and the epidote may be pyrogenetic in origin. In other Victorian examples showing less definite epidote-orthite associations, the epidote is an alteration product of the orthite, but instead of having clearly defined prisms of epidote produced as in the Yackandandah occurrence, the angles of the crystals consist of a fine-grained mixture of orthite and epidote (figs. 10 and 19), showing mottled polarization colours. In such examples, the interiors of the orthite crystals have become almost isotropic.

The Origin of the Orthite.

Clarke states that orthite is widely diffused as a primary accessory mineral in many igneous rocks (2), and Dana records it in albitic and common felspathic granites (3). On the other hand, Watson states that orthite may be formed by contact metamorphism (13, p. 465), and he records it as locally abundant in marginal facies of some Montana, U.S.A. granitic batholiths at contacts with sediments. He considers that when formed as a product from the consolidation of a molten magma, the mineral is invariably in small grains and crystals of microscopic size. Mennell regards the orthite in the granites of Northern Rhodesia as a normal product of consolidation on account of the idiomorphic nature of the crystals in contact with mica, and he records associated minerals as sphene, hornblende, and abundant epidote (10, p. 4).

The orthite crystals in the granitic rocks of Victoria are of microscopic dimensions, and are idiomorphic towards biotite, hornblende, sphene, quartz, and felspar, so that according to Watson's and Mennell's statements, they would be formed as primary accessories from the consolidation of a molten mass. This may apply to some of the Victorian occurrences, but not to all of them.

Some of the orthite crystals contain inclusions of zircon, apatite, and rutile, so that the orthite crystallized after these accessory minerals. Since it is idiomorphic towards the other constituents, its position in the order of crystallization in these examples, is between that of the accessory and ferromagnesian minerals. The orthite therefore appeared early in the sequence of consolidation, this being in agreement with Hobbs' statement that allanite is one of the earliest separations from the magma (4, p. 228). Iddings and Cross record sphene as an inclusion in allanite, and state that the inclusions are found in such connection as to indicate contemporaneous growth (6, p. 110). In Victorian examples, sphene is only observed moulded on orthite crystals (figs. 7 and 12), so that the orthite crystallized before sphene.

In foreign xenoliths of igneous origin in the You Yangs granite (1), orthite includes grains of diopside which have been produced as a result of reconstitution processes within the xenoliths. The crystals of orthite in this granite are therefore probably xenocrysts obtained from the xenoliths. In the basic schlieren in the Tynong granite, hornblende, biotite, and sphene are plentiful and some orthite is present, but in portions of this granite which show little or no evidence of contamination, hornblende and orthite are wanting, and sphene and biotite subordinate in amount compared with their occurrence in the schlieren. It therefore appears that the sphene and ferromagnesian minerals were developed as a result of contamination, and became strewn about through parts of the granite. Since the orthite is intimately associated with these minerals, it may also have resulted in like manner, and so would be assigned a contamination mode of origin. Where orthite occurs in contaminated granitic rocks, but has not been observed in the xenoliths associated with them, it may be that the orthite crystals developed in the granite magma only after it had become contaminated by the addition of foreign material. Orthite that occurs in granitic rocks showing no evidence of contamination is most probably a primary accessory mineral. Examples of such are the granites of Stawell, Mount Wycheproof, and the outcrop at the junction of the Mitta Mitta River and the Bundarrah River, and in them, zonal alteration of orthite is subordinate, and crystals are much smaller than those developed in granitic rocks which provide definite evidence of contamination by assimilation.

In the Tynong and You Yangs granites, it has been shown that sphene, hornblende, and biotite may arise from contamination processes, and that, since orthite is intimately associated with these minerals, it also may develop from similar processes. Several other Victorian granitic rocks which possess sphene, hornblende, and biotite thought to have been derived by assimilation of foreign material, were examined for the mineral orthite and found to contain no trace of it. In addition, examination of several sections of the contaminated granites of North-Eastern Victoria (12), and basic clots from the Maldon and Pyramid Hill granites, failed to reveal orthite; neither was it observed in the granite itself from these last two localities; such rocks are free from hornblende and contain very little sphene. From the foregoing evidence, the conclusion is that although orthite is commonly associated with hornblende, sphene and biotite in some of the Victorian granitic rocks which have suffered contamination, the presence of these minerals does not necessarily imply the presence of orthite.

The variability in the composition of the orthite is probably due to the chemical attack of the magma, which resulted in embayment of crystal contours, zonal alteration, partial or complete destruction of internal structure and decolouration from leaching out of iron. The zones with a rust-like appearance in some of the orthites may have developed as a result of successive pauses during crystal growth. An already formed crystal may have been partially decolourized by leaching out of iron, and the oxides so formed deposited in the peripheral zone of the crystal. Continuation of crystallization may then build up the crystal, and the newly formed zone may again be subjected to leaching with the deposition of another rust-like zone in the periphery of the crystal. Repetition of these processes would result in the development of three or four alternating zones of rust-like material and pale coloured orthite. The same processes may have resulted in the production of those crystals which possess fresh pleochroic cores and remnants alternating with pale coloured orthite, but in them, leaching was not complete.

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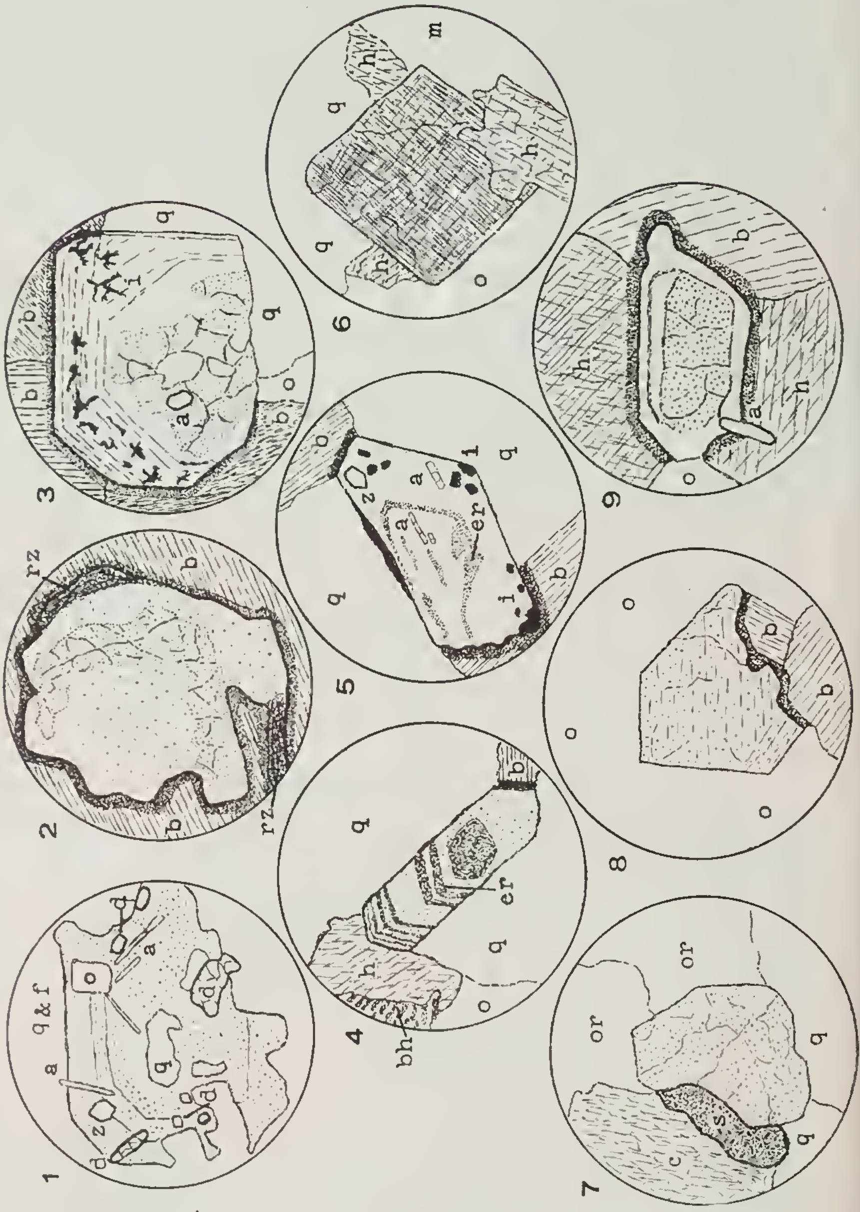
Explanation of Figures.

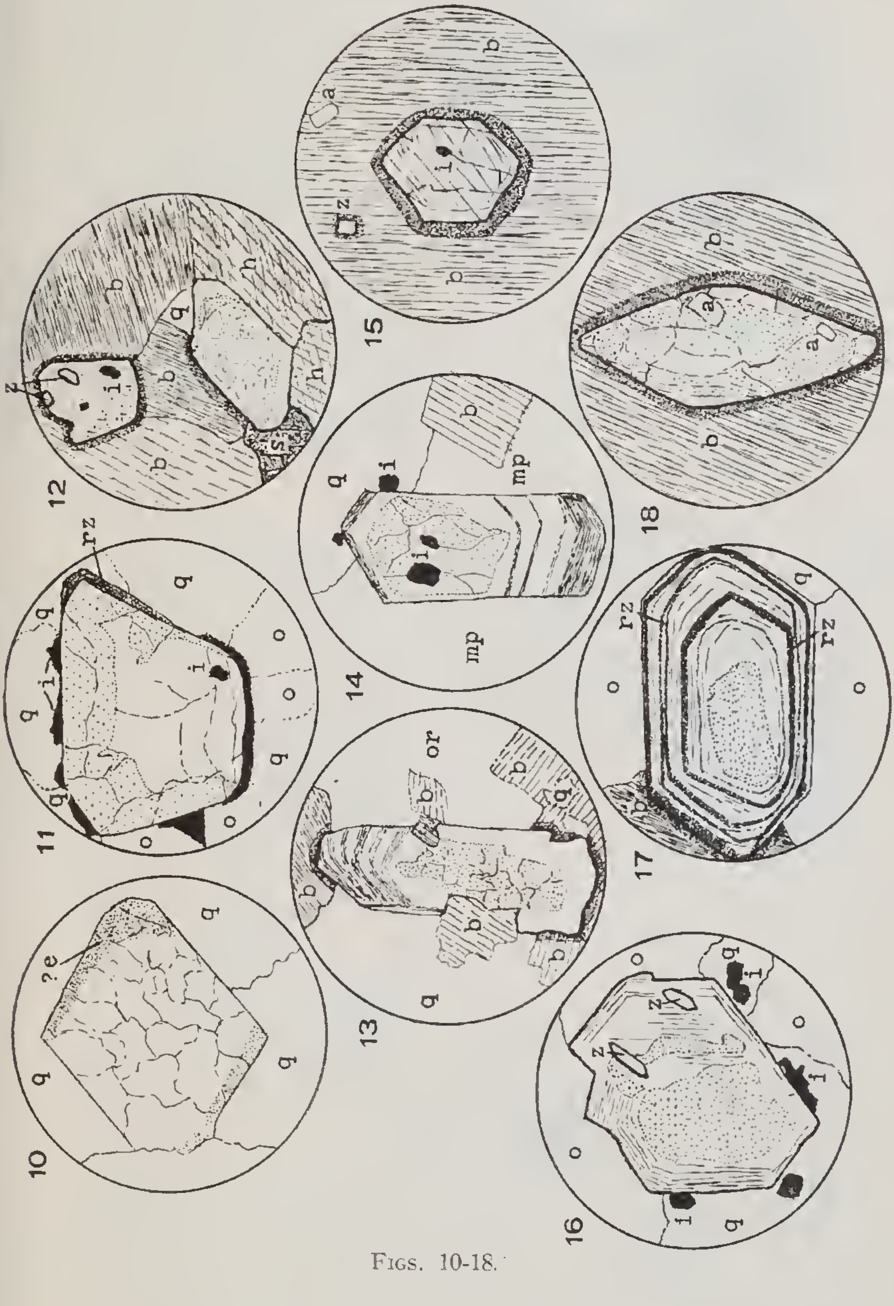
SKETCH MICROSECTIONS OF ORTHITE SHOWING FORM AND MINERAL ASSOCIATIONS. a — apatite, z — zircon, q — quartz, f — felspar, d — diopside, b — biotite, i — iron oxides, o — oligoclase, m — microcline, bh — biotite dactylitic with hornblende, h — hornblende, c — chlorite, s — sphene, or — orthoclase, e — epidote, mp — microperthite, r — rutile, rz — rust-coloured zone, er — "earthy" material, fe polarizing aggregate, probably of epidote.

1. Inclusions of diopside, apatite and zircon in crystal corroded in contact with quartz and felspar. Xenolith, You Yangs. × 75.
2. Corroded crystal with cracked pleochroic remnants, included in biotite, and possessing an outer rust-coloured zone and a pleochroic halo against biotite. Granite, You Yangs. × 75.
3. Dendritic inclusions of iron oxide in the outer zones of a crystal showing (001), (100) and (110) faces, with one edge imperfectly developed. Basic schlieren, You Yangs. × 35.
4. "Chevron-like" zoning of "earthy" material in prismatic crystal. Pleochroic against biotite, but non-pleochroic against hornblende. Basic schlieren, You Yangs. × 35.
5. "Earthy" products and inclusions in prismatic crystal showing ragged termination. Basic schlieren, You Yangs. × 35.
6. Red-coloured, diamond-shaped crystal, non-pleochroic against hornblende. Granite, You Yangs. × 75.
7. Irregular-shaped crystal associated with sphene and chlorite. Granite, Maude. × 75.
8. Stumpy-prismatic crystal with ragged contact and pleochroic against biotite. Granodiorite, South Morang. × 75.

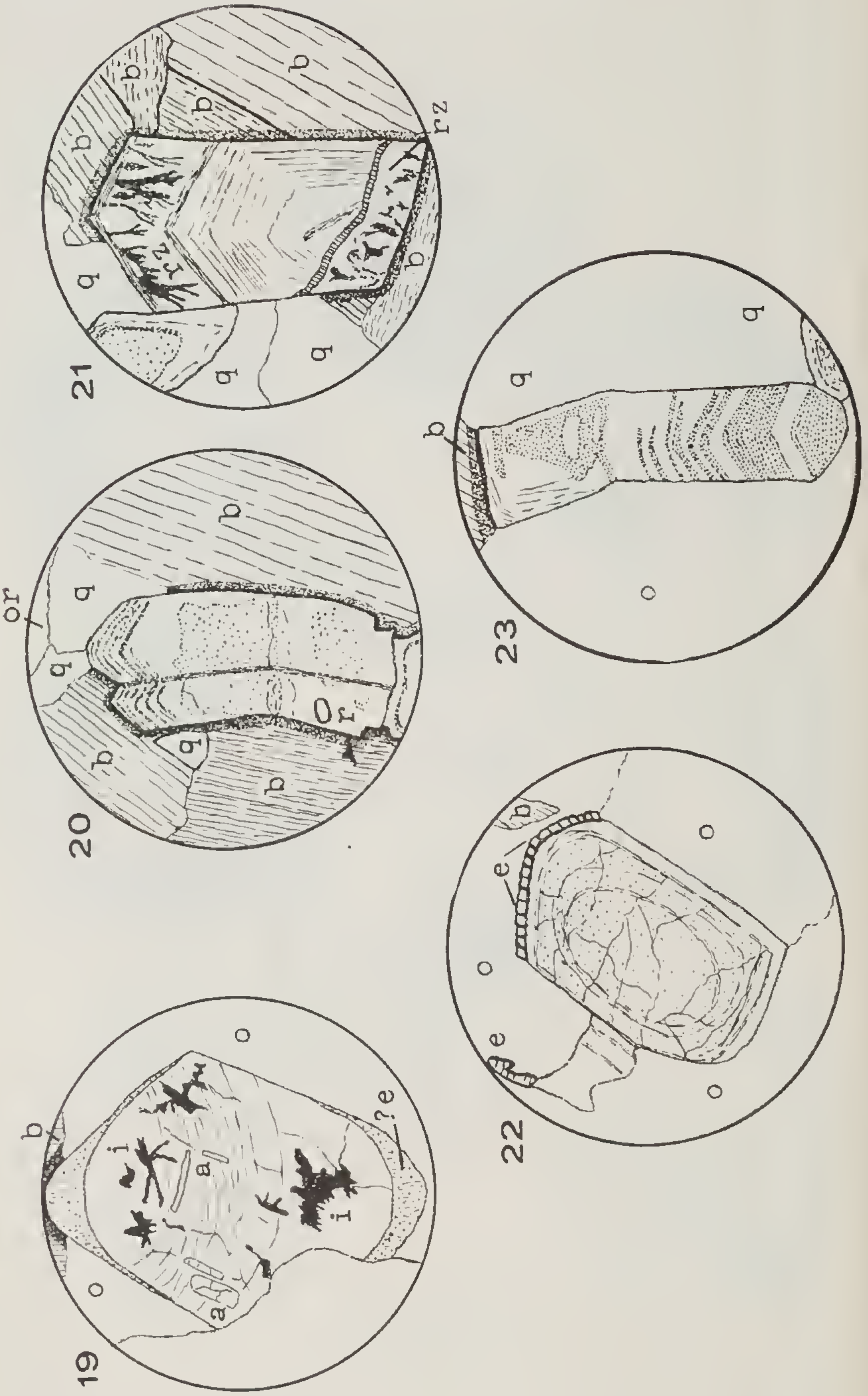
9. Brown pleochroic core surrounded by a green outer rim, and enclosed by hornblende and biotite, with pleochroic haloes against both. Granodiorite, Mt. Eliza. × 75.
10. Diamond-shaped crystal with irregular cracks and more highly birefringent marginal material (probably epidote decomposition products). Granite, You Yangs. × 75.
11. Isotropic core surrounded by a birefringent appregate, with an incomplete fringe of iron oxides. Xenolith, You Yangs. × 75.
12. Two orthite crystals associated with hornblende, sphene and biotite, in a ferromagnesian clot. Granite, You Yangs. × 35.
13. Pleochroic core with irregular cracks in prismatic crystal showing "chevron-like" zoning in the paler coloured outer zones. Granite, You Yangs. × 35.
14. Prismatic crystal associated with iron oxide, set in microperthite and with "chevron-like" zoning. Granite near contact with xenolith, You Yangs. × 35.
15. Small crystal with pleochroic halo, completely enclosed in a large biotite plate. Granite near contact with xenolith, You Yangs. × 75.
16. Pleochroic remnants of fresh material in zoned crystal. Granite near contact with xenolith, You Yangs. × 35.
17. Prismatic crystal with red interior and rust-coloured zones parallel to the external form. Granite near contact with xenolith, You Yangs. × 75.
18. Lens-shaped crystal with halo, completely enclosed in biotite. Basic schlieren, You Yangs. × 75.
19. Cross section of a crystal with curved cracks, dendritic iron oxide, isotropic centre and birefringent angles. Basic schlieren. You Yangs. × 75.
20. Twin crystal showing "composition seam" and "chevron-like" zoning. Basic schlieren. You Yangs. × 35.
21. Dendritic iron oxide in outer zones of a prismatic crystal, with parallel zoning and pleochroic haloes against biotite. Broken outer zone at bottom of crystal indicates that such zones are three dimensional. Basic schlieren, You Yangs. × 35.
22. Prismatic crystal with irregular protuberance and a fringe of epidote at one end. Granodiorite, Yackandandah. × 35.
23. "Chevron-like" zoning of fresh pleochroic material in prismatic crystal. Granite, Tynong. × 75.



Figs. 1-9.



Figs. 10-18.



Figs. 19-23.